Defense Threat Reduction Agency
8725 John J. Kingman Road, MS-6201
Fort Belvoir, VA 22060-6201

DTRA-TR-16-070

TECHNICAL REPORT

Evaluation of Radiation Exposure Hazard from Squaw Targets Used in Operations WIGWAM and HARDTACK-I

DISTRIBUTION A. Approved for public release: distribution is unlimited.

July 2016

Prepared by:

Leidos, Inc.
Reston, VA

This page intentionally left blank.

REPORT DOCUMENTATION PAGE	*Form Approved* **OMB No. 0704-0188**

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
11-07-2016	Technical Report	

4. TITLE AND SUBTITLE Evaluation of Radiation Exposure Hazard from Squaw Targets Used in Operations WIGWAM and HARDTACK-I	**5a. CONTRACT NUMBER** HDTRA1-15-C-0002
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Egbert, Stephen and McKenzie-Carter, Michael	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Leidos, Inc. 11951 Freedom Drive Reston, VA 20190	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Nuclear Technology Department, Attn: Dr. Blake Defense Threat Reduction Agency 8725 John J. Kingman Road, Mail Stop 6201 Fort Belvoir, VA 22060-6201	**10. SPONSOR/MONITOR'S ACRONYM(S)** DTRA J9
	11. SPONSORING/MONITORING AGENCY REPORT NUMBER DTRA-TR-16-070

12. DISTRIBUTION AVAILABILITY STATEMENT
DISTRIBUTION A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In 2011, a sunken vessel was discovered by divers near San Clemente Island, CA. It was conjectured by fellow divers that the vessel was a Squaw target that had been used in underwater nuclear testing. This report was prepared to address possible future concerns by members of the public in the event that the vessel that was discovered is one of the Squaw targets used during Operations WIGWAM and HARDTACK-I. The report describes the use of the three Squaw targets during underwater nuclear testing, the loss of two of the Squaws in deep ocean water, and the later use of the third Squaw as a sonar target. The possibility of radiological contamination of the third Squaw during its use in nuclear testing and the potential for a radiation exposure hazard are evaluated and discussed.

15. SUBJECT TERMS
Squaw target, Operation WIGWAM, Operation HARDTACK-I, underwater nuclear testing radiation hazard

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Paul K. Blake, PhD
a. REPORT	**b.** ABSTRACT	**c.** THIS PAGE	U	19 Pages	**19b. TELEPONE NUMBER (*Include area code*)** (703) 767-3433
U		U			

UNIT CONVERSION TABLE

U.S. customary units to and from international units of measurement*

U.S. Customary Units	Multiply by → / ← Divide by†		International Units
Length/Area/Volume			
inch (in)	2.54	$\times 10^{-2}$	meter (m)
foot (ft)	3.048	$\times 10^{-1}$	meter (m)
yard (yd)	9.144	$\times 10^{-1}$	meter (m)
mile (mi, international)	1.609 344	$\times 10^{3}$	meter (m)
mile (nmi, nautical, U.S.)	1.852	$\times 10^{3}$	meter (m)
barn (b)	1	$\times 10^{-28}$	square meter (m^2)
gallon (gal, U.S. liquid)	3.785 412	$\times 10^{-3}$	cubic meter (m^3)
cubic foot (ft^3)	2.831 685	$\times 10^{-2}$	cubic meter (m^3)
Mass/Density			
pound (lb)	4.535 924	$\times 10^{-1}$	kilogram (kg)
unified atomic mass unit (amu)	1.660 539	$\times 10^{-27}$	kilogram (kg)
pound-mass per cubic foot (lb ft^{-3})	1.601 846	$\times 10^{1}$	kilogram per cubic meter (kg m^{-3})
pound-force (lbf avoirdupois)	4.448 222		newton (N)
Energy/Work/Power			
electron volt (eV)	1.602 177	$\times 10^{-19}$	joule (J)
erg	1	$\times 10^{-7}$	joule (J)
kiloton (kt) (TNT equivalent)	4.184	$\times 10^{12}$	joule (J)
British thermal unit (Btu) (thermochemical)	1.054 350	$\times 10^{3}$	joule (J)
foot-pound-force (ft lbf)	1.355 818		joule (J)
calorie (cal) (thermochemical)	4.184		joule (J)
Pressure			
atmosphere (atm)	1.013 250	$\times 10^{5}$	pascal (Pa)
pound force per square inch (psi)	6.984 757	$\times 10^{3}$	pascal (Pa)
Temperature			
degree Fahrenheit (°F)	[T(°F) − 32]/1.8		degree Celsius (°C)
degree Fahrenheit (°F)	[T(°F) + 459.67]/1.8		kelvin (K)
Radiation			
curie (Ci) [activity of radionuclides]	3.7	$\times 10^{10}$	per second (s^{-1}) [becquerel (Bq)]
roentgen (R) [air exposure]	2.579 760	$\times 10^{-4}$	coulomb per kilogram (C kg^{-1})
rad [absorbed dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [gray (Gy)]
rem [equivalent and effective dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [sievert (Sv)]

*Specific details regarding the implementation of SI units may be viewed at http://www.bipm.org/en/si/.

†Multiply the U.S. customary unit by the factor to get the international unit. Divide the international unit by the factor to get the U.S. customary unit.

Table of Contents

List of Figures

Executive Summary

In 2011, a sunken vessel was discovered by divers near San Clemente Island, CA, that was thought to be a "Squaw" target that was used in underwater nuclear testing in the 1950s. Because it is possible that the vessel discovered by the divers is one of the Squaw targets, this technical report was prepared to address possible future questions from members of the public about this sunken vessel. The purpose of this report is to describe the use of Squaw targets during and after underwater nuclear testing, the potential for their contamination during the testing, and an evaluation of whether the sunken vessel discovered near San Clemente Island could present any current radiation exposure hazards.

Three 4/5-scale model submarine hulls (called "Squaws") were built for the U.S. Navy in 1954 for use as submerged targets for hull-damage testing at Operation WIGWAM, a deep underwater nuclear test conducted in 1955 at a location over 600 miles west-southwest of San Diego, CA. At the time of the Operation WIGWAM detonation, the three Squaws were located at distances from 5,200 feet to 10,100 feet upwind and upcurrent from surface zero. One Squaw target, SQUAW-12, sank at the Operation WIGWAM test area, and a second, SQUAW-13, sank in deep water at a location over 200 miles west-southwest of San Diego while under tow. The third target, SQUAW-29, was not damaged and was towed to San Diego.

In 1958, SQUAW-29 was used again as a target in nuclear testing at Enewetak Atoll in the Pacific Proving Ground during Operation HARDTACK-I. This Squaw was submerged at a distance of 1,680 feet from surface zero of the UMBRELLA detonation. It was not severely damaged and there is no record of its contamination following Shot UMBRELLA. Following its use at Operation HARDTACK-I, SQUAW-29 was towed to Pearl Harbor and eventually to Long Beach Naval Shipyard.

Following repair and refurbishment, SQUAW-29 was used during the period 1959–1978 as a submerged sonar target off the coast of San Diego. In September 1978, the Navy directed that the Squaw be disposed of. However, neither a record nor a description of the Squaw's final disposition could be located, and it is possible that the vessel discovered near San Clemente Island is SQUAW-29.

No records of radiological measurements made on SQUAW-29 were located, and no mention of it being contaminated could be found in historical reports reviewed for this technical report. In order to evaluate whether this target might present a current or future radiological hazard to divers or other individuals, two potential pathways for its possible contamination during Operations WIGWAM and HARDTACK-I were evaluated. Because of the intervening water between SQUAW-29 and each of the two detonations where it was used, neutron activation was unlikely, and any small potential amount of induced radioactivity would have decayed to insignificant levels by 2011. Possible contamination of the SQUAW-29's surfaces by fission products suspended in the water surrounding the Squaw was also evaluated. High-sided hypothetical estimates of this possible contamination and exposure pathway resulted in insignificant calculated exposure rates in air in 2011. Estimated exposure rates would be even lower if the scrubbing action of ocean water and the shielding effects of water currently surrounding the submerged vessel were considered. Therefore, if the vessel discovered by divers is in fact SQUAW-29, it is concluded that there are no potential exposure hazards to divers or to individuals on the ocean surface above the sunken vessel.

Section 1.

Background

In April 2014, the Defense Threat Reduction Agency (DTRA) received a public inquiry from the media regarding a large sunken vessel that underwater divers discovered on February 13, 2011 (Madden, 2014). The sunken vessel was discovered at a depth of approximately 300 feet (ft) near San Clemente Island (Marco, 2015), which is located approximately 75 miles (mi) west of San Diego, CA. The conjecture in the inquiry was that the vessel was a “Squaw” target that was lost following Operation WIGWAM in 1955. One of the divers who found the vessel in 2011 posted the following comment accompanying a video of the vessel on an internet website (Rebreather World, 2011):

> Dove this on February 13, 2011. We thought it was a WWII US Sub but after diving it and looking at the video, I'm not sure what it is? No torpedo tubes, no propellers, no rudder, no conning tower. Any ideas?

Within a week the vessel was identified by fellow divers as an Operation WIGWAM Squaw.

Three Squaw target vessels were built and used in the underwater nuclear test during Operation WIGWAM. Two of these Squaws were lost in the open ocean shortly after Operation WIGWAM. The third Squaw was used again as an underwater target during Operation HARDTACK-I, after which it was refurbished and used as a sonar target for many years. The ultimate fate of the third Squaw could not be determined. It is possible that the vessel discovered by divers is in fact the third Squaw. Neither the public inquiry nor the website comments raised concerns about potential radiological exposure hazards from the sunken vessel. However, in the course of preparing responses to the inquiry, discussions ensued about whether there could be any public safety issues resulting from the possible discovery of a lost Squaw. Therefore, this technical report was prepared to address potential questions from members of the public about the possibility of radiation hazards from this sunken vessel in the event it is in fact a Squaw target.

Section 2.

History of the Squaw Targets

Three 4/5-scale model submarine hulls (called “Squaws”) were built in 1954 at the Long Beach Naval Shipyard and were delivered to the U.S. Naval base at San Diego, CA (Focke, 1980; Ross, 1955). Each identical Squaw (Figure 1) had approximate dimensions of 135 ft in length, 23 ft in height, and 20.5 ft in breadth (Ross, 1955; NAVSHIPS, circa 1971). The Squaw hulls were to be used as submerged targets during hull-damage testing at the underwater nuclear detonation at Operation WIGWAM, a deep underwater nuclear test conducted as part of the 1945–1962 United States series of atmospheric nuclear tests (DTRA, 2014; USAF, 1955).

In preparation for the Operation WIGWAM test, the three Squaws were towed to the Operation WIGWAM location to be submerged for the test as shown in Figure 2. That location was planned to be about 500 mi southwest of San Diego, CA, but because of weather conditions, the final location was over 600 mi west-southwest of San Diego as shown in Figure 3 (DNA, 1955). At the time of the 30 kiloton (kt) Operation WIGWAM detonation on May 14, 1955 at a depth of 2,000 ft, the two Squaws that were closest to surface zero (designated SQUAW-12 and SQUAW-13) were submerged at a depth of approximately 250 ft, and were located at distances of approximately 5,200 ft and 7,300 ft from surface zero, respectively (Figure 4).

Because of damage that occurred during towing, the third target (SQUAW-29), could not be submerged and remained on the surface of the water at approximately 10,100 ft from surface zero of the nuclear device. All Squaws were located upwind and upcurrent from surface zero. The target closest to the Operation WIGWAM device, SQUAW-12, collapsed as a result of damage from the detonation and sank at the Operation WIGWAM test area very shortly after the detonation (Focke, 1980). Within the few days following the Operation WIGWAM test, SQUAW-13 and SQUAW-29 were disassembled from the test array and prepared to be towed from the test area to White Cove, Santa Catalina Island, CA. While being towed to White Cove, the cabling attached to SQUAW-13 severed and the target sank at a location over 200 mi west-southwest of San Diego, roughly 150 mi west-southwest of San Clemente Island in water over 10,000 ft deep (Figure 3) (Focke, 1980; NOAA, 2015). The remaining Squaw, SQUAW-29, was successfully towed to San Diego (DNA, 1955; Weary et al., 1981).

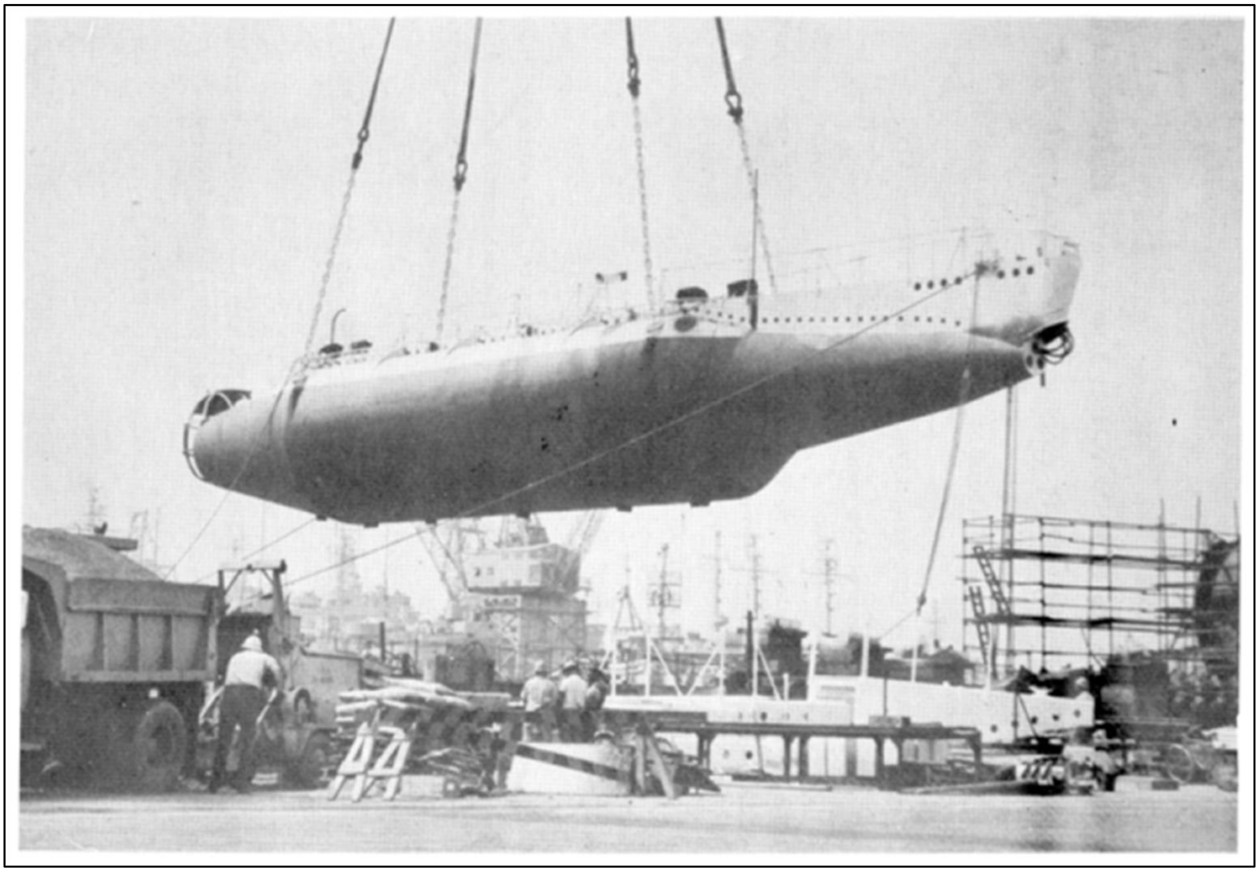

Figure 1. Launching of a Squaw

(Weary et al., 1981, Figure I-7)

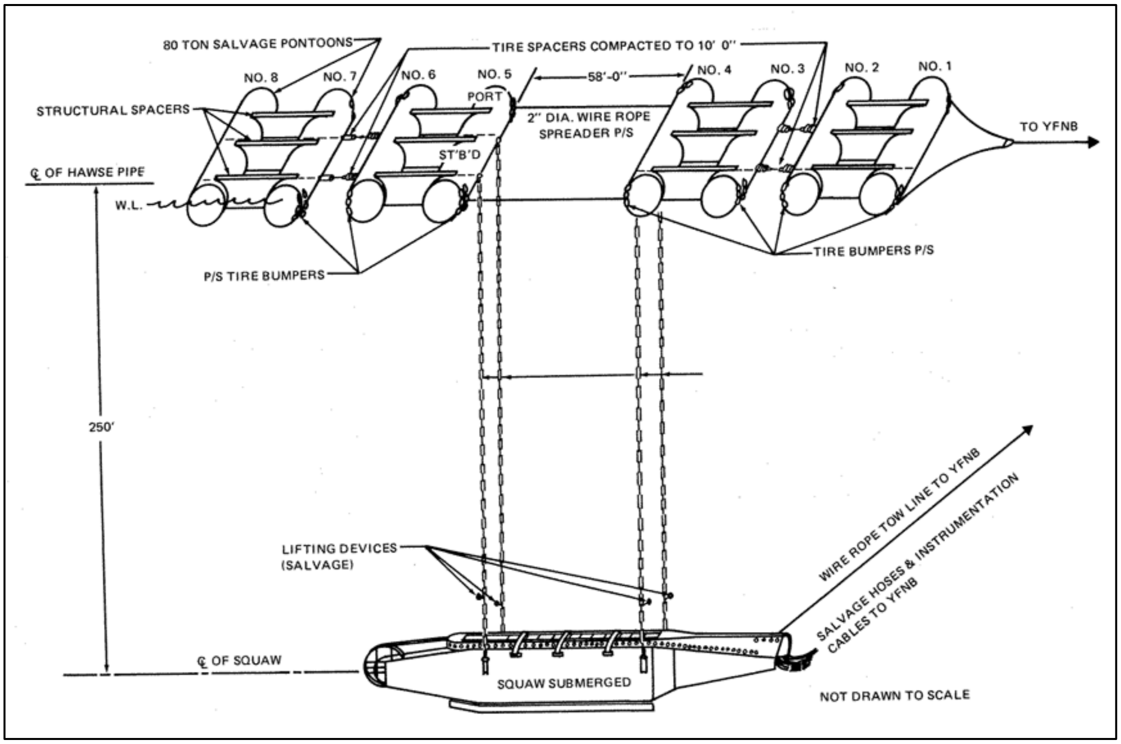

Figure 2. Suspension arrangements for the Squaw targets at Operation WIGWAM

(Weary et al., 1981, Figure I-9)

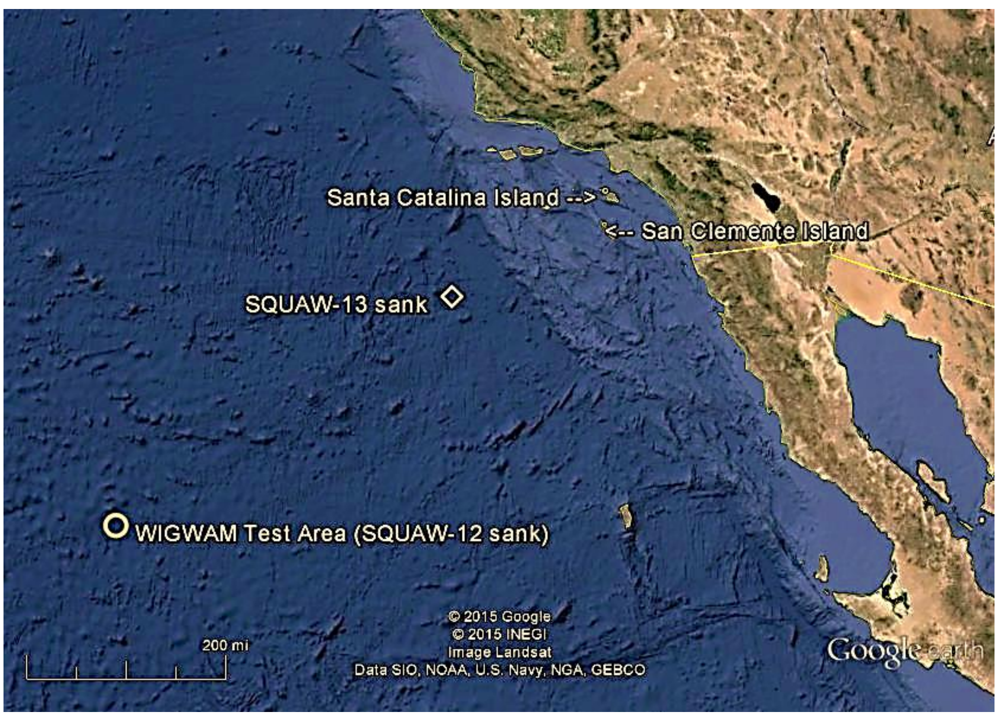

Figure 3. Operation WIGWAM test area and locations where two Squaws sank

(DNA, 1955; Focke, 1980)

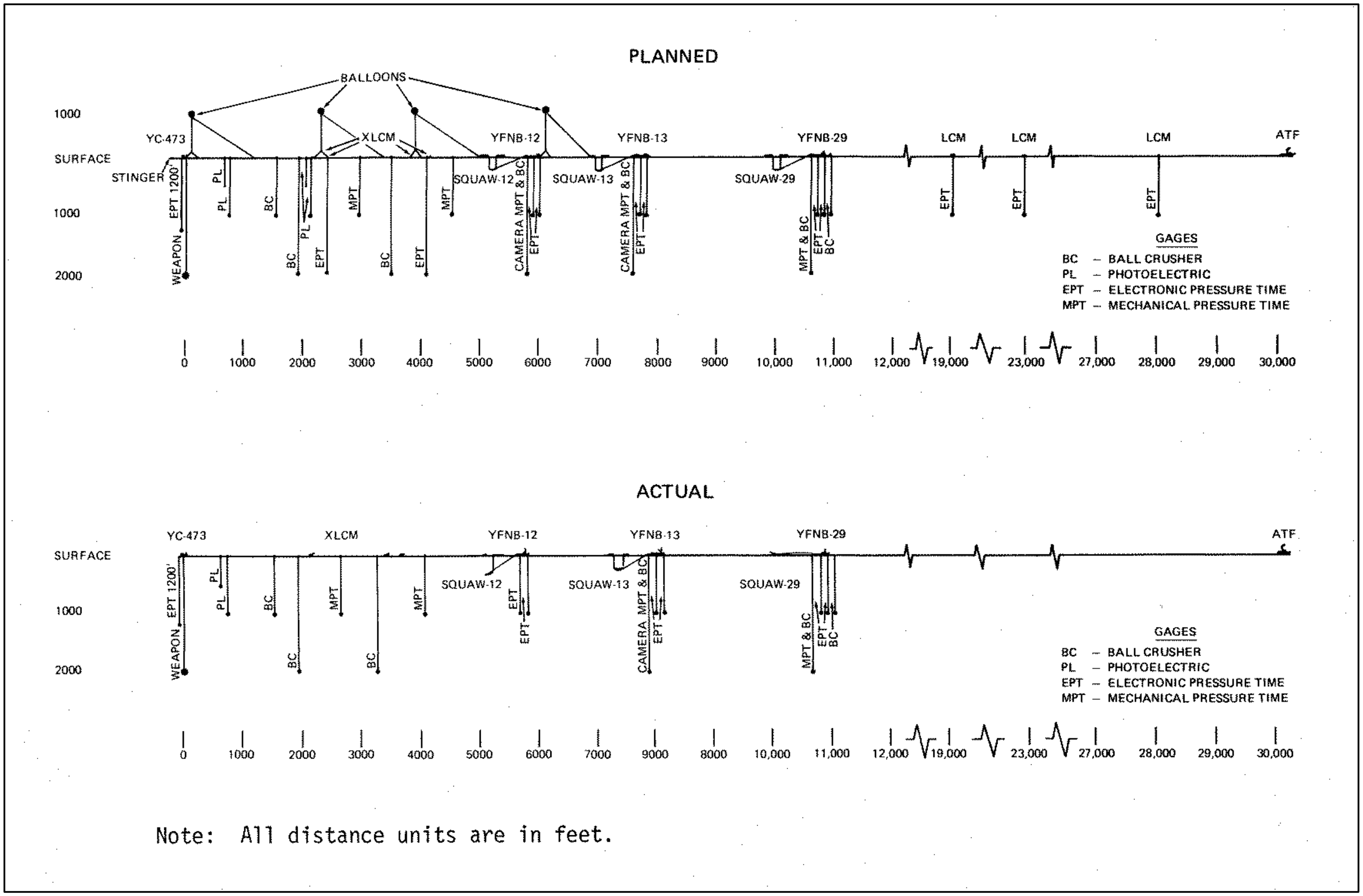

Figure 4. Planned and actual target array, Operation WIGWAM

(Weary et al., 1981, Figure 1-4)

In 1958, SQUAW-29 was used again as a submerged target at a nuclear detonation. This took place at Enewetak Atoll in the Pacific Proving Ground during Operation HARDTACK-I. The Squaw was towed to Enewetak prior to Operation HARDTACK-I, and on June 9, 1958, it was submerged at a distance of 1,680 ft (originally planned to be 1,600 ft) from surface zero of the 8 kt underwater Shot UMBRELLA, which was placed on the bottom of the Enewetak Lagoon at a depth of 140 ft (Figure 5). Although SQUAW-29 was damaged as a result of the UMBRELLA detonation, the damage was not as severe as was expected (Rich et al., 1985). There is no record of any contamination on SQUAW-29 following Shot UMBRELLA and decontamination was not necessary. On the afternoon of the following day it was resurfaced, boarded after being determined as radiologically safe, and towed to the south end of Enewetak Lagoon. On June 22, SQUAW-29 departed Enewetak under tow for Pearl Harbor for damage inspection. (Gladeck et al., 1982)

Following its use in Operation HARDTACK-I, SQUAW-29 was refurbished and placed into service as a submerged sonar target. In 1959, 1965, and 1970, SQUAW-29 was moored at depths of 200 ft and 300 ft at various distances off the coast of San Diego. Each of these moorings lasted about five years and ended with the Squaw re-surfacing. The Squaw was repaired and refurbished at the Long Beach Naval Shipyard after each mooring failure. No record or mention of any radiological contamination was located for this period of use and refurbishment. A final mooring was attempted in 1978 but was unsuccessful. The Squaw was towed to the Naval Station at San Diego where it underwent successful submergence tests. In September 1978, the Commander in Chief, Pacific Fleet, directed that the Squaw Mooring Project be terminated and that the Squaw be disposed of. Documentation of the Squaw's final disposition could not be located for this report. (CHESNAVFACENGCOM, 1978)

Section 3.

Evaluation of Potential Radiation Exposure

Based on the documented sinking of two Squaw targets following Operation WIGWAM and the subsequent use of the third Squaw during and after Operation HARDTACK-I, the vessel located by divers is not SQUAW-12 or SQUAW-13, but it may be SQUAW-29. There are no known records of radiological measurements made on SQUAW-29, and no mention of it being contaminated could be found in historical reports. Therefore, in order to evaluate whether this target might present a current or future radiological hazard to divers or other individuals, the potential for its possible contamination during Operations WIGWAM and HARDTACK-I were investigated. There are two pathways that can be considered for possible radiological contamination of SQUAW-29: 1) neutron-induced activation of the Squaw outer shell and other components, and 2) surface contamination from fission products.

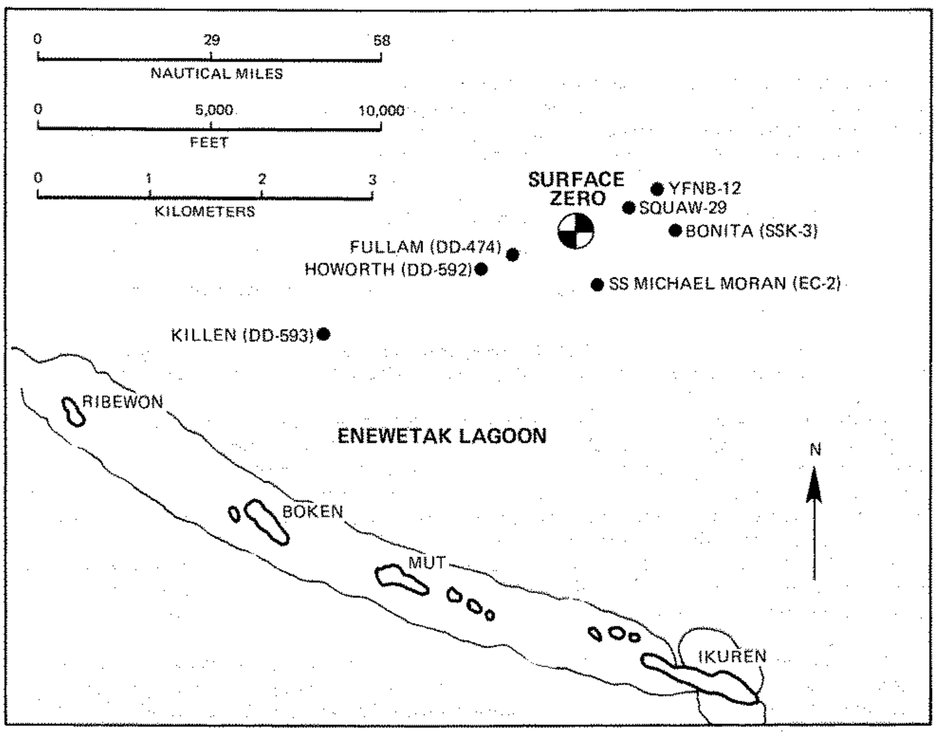

Figure 5. Target array at Operation HARDTACK-I Shot UMBRELLA

(Gladeck et al., 1982)

3.1 Radiation from Neutron-Induced Activation

At the time of the Operation WIGWAM detonation in 1955, SQUAW-29 was on the water surface and was separated horizontally by 10,100 ft from surface zero of the Operation WIGWAM device, which was set at a depth of 2,000 ft (Weary et al., 1981). Figure 4 illustrates the array setup of the Squaws at the time of the Operation WIGWAM detonation. The

SQUAW-29 slant separation from the Operation WIGWAM device was 10,296 ft. At the time of the UMBRELLA detonation in 1958, SQUAW-29 was submerged and separated horizontally by about 1,680 ft from surface zero of the UMBRELLA device (Gladeck et al., 1982). Figure 5 illustrates the array setup of the SQUAW-29 at the time of the UMBRELLA detonation.

The potential for neutron activation of the Squaw was dependent upon the neutron fluences at the locations of the Squaw, which was determined by the release of neutrons from the detonations and the attenuating effects of the intervening water. Because water is an effective attenuator of neutrons, neutrons have a short range in water. Every foot of water reduces the fast (1-MeV) neutron fluence by 100 to 1000 times (Schaeffer, 1973). The minimum slant range of SQUAW-29 at the two detonations was about 1,680 ft of intervening lagoon water at UMBRELLA. However, the path of least shielding for neutrons at UMBRELLA was upward from the device through 140 ft of lagoon water, outward from surface zero through air for about 1,680 ft, and then down to the submerged Squaw. The thickness of water in this path of least shielding would effectively eliminate the possibility of any consequential neutron fluence at the location of the Squaw from UMBRELLA. The thickness of water in the path of least shielding for the Squaw at the earlier Operation WIGWAM detonation was much more than it was at UMBRELLA (2,000 ft of ocean water), and the potential for activation of the Squaw from the Operation WIGWAM detonation was much less because of more intervening ocean water.

Even if any hypothetical neutron activation of the Squaw occurred, there would have been significant radiological decay of induced radioisotopes prior to its apparent discovery in 2011. The primary long-lived gamma-emitting radioisotopes induced in steel are Fe-55 (half-life = 1,002 days) from iron and Co-60 (half-life = 1,926 days) from a small concentration of cobalt possibly used in the making of the steel. The succeeding radiological decay over more than 50 years from the date of Shot UMBRELLA would have reduced the hypothetical exposure rate from activated steel by factors of 570,000 for Fe-55 and 1,000 for Co-60 (NNDC, 2015).

Because of the intervening water between SQUAW-29 and the Operation WIGWAM and UMBRELLA detonations, neutron activation was extremely unlikely, and any small potential amount of induced radioactivity would have decayed to insignificant levels by 2011. Therefore, there would be no residual radiation hazard from the Squaw's potential neutron activation.

3.2 Radiation from Residual Fission Products

Fission products released from the Operation WIGWAM device were dispersed into the ocean and air after the detonation in a direction away from SQUAW-29 and most of the supporting ships. At Operation WIGWAM, only two ships, YAG-39 and YAG-40, were contaminated with measurable levels of radioactivity (Weary et al., 1981). These ships operated toward the south-southwest of surface zero, downwind and down ocean current from the Operation WIGWAM device. At the time of the Operation WIGWAM detonation, the Squaws were lined up due north of the device, upwind and upcurrent, with SQUAW-29 located 10,100 ft from surface zero (Weary et al., 1981). The base surge and surface pool of radioactive debris from the Operation WIGWAM detonation did not reach upwind or upcurrent more than 6,000 ft (Weary et al., 1981; Focke, 1980). The SQUAW-29 target survived the detonation intact (Focke, 1980) and was not contaminated following Operation WIGWAM (Weary et al., 1981).

At UMBRELLA, the lagoon water in the vicinity of SQUAW-29 mooring was contaminated by fission products. However, no record of contamination of this Squaw could be found, and all contaminated ships and targets at UMBRELLA were successfully decontaminated (Gladeck et al., 1982). Nevertheless, if some of the fission products that initially dispersed in the lagoon following UMBRELLA did adhere to the SQUAW-29 surface, this still would not have resulted in a significant hazard in the hours and days following the detonation or in 2011 when the Squaw was allegedly discovered. This can be demonstrated using a hypothetical scenario to conservatively estimate potential surface contamination of SQUAW-29 by fission products from UMBRELLA. For this scenario, it is assumed that the fission products production ratio is 15 MCi kt^{-1} at H+24 (Hicks, 1982), that the overall radioactivity in the water was spread out uniformly in a cylinder of lagoon water with a radius of approximately 8,200 ft (Gladeck et al., 1982) and a height (ocean depth) of 140 ft from the water surface down to the device, and that all fission products within a foot of the outer surface of SQUAW-29 adhered to its outer skin. Assuming no reduction of contamination from any processes other than radiological decay, and using a standard fission product decay function of $(\text{time})^{-1.2}$ for the first 6 months and $(\text{time})^{-2.2}$ thereafter (DTRA, 2010, ED02) would result in an estimate of surface contamination of less than 10^{-9} Ci ft^{-2} in 2011 when the Squaw is presumed to have been discovered by the divers at San Clemente Island. Assuming a high-sided value for the gamma constant of 16 rad h^{-1} per Ci m^{-2} at 1 meter for 1-MeV photons (Voss, 2001) results in a gamma dose rate in air at 1 meter from the surface of SQUAW-29 of less than 10^{-4} mrad h^{-1} in 2011. To illustrate that this hypothetical model likely overestimates any actual contamination, the estimated dose rate in 2011 implies a dose rate of approximately 750 mrad h^{-1} at the time of initial recovery and salvage activities on the Squaw following UMBRELLA. It is likely that such a dose rate would have been reported prior to any boarding by the salvage crew, but no record of this was located.

Moreover, towing SQUAW-29 across thousands of miles of open ocean would have reduced the amount of any contamination that potentially adhered to its surface by orders of magnitude if not completely. This effect was demonstrated during Operation WIGWAM by the simple water washdown systems on YAG-39, on which the radiation reading on the deck was reduced from 400 R h^{-1} to 0.040 R h^{-1} in less than 15 minutes (Weary et al., 1981). Furthermore, the effects of corrosion and the action of ocean currents on SQUAW-29 while submerged for decades in ocean water would have acted to remove any remaining contamination.

Section 4.

Summary and Conclusions

The vessel discovered by divers near San Clemente Island in 2011 may be the SQUAW-29 target used during U.S. atmospheric nuclear testing in 1955 and 1958. The Squaw does not present a radiological hazard because neither of the two contamination pathways discussed in Section 3 could result in a potential exposure hazard. Neutron activation of the body of the Squaw was very unlikely because of separation distances and the intervening water between the nuclear devices and the locations of this target at the times of detonations. As for potential residual surface contamination, SQUAW-29 was located in non-contaminated water after the Operation WIGWAM detonation and was not found to be contaminated after the UMBRELLA detonation. Even if there had been a low level of contamination, there would currently be no potential hazard presented by any fission products of SQUAW-29 because any contamination would have been completely removed after towing it through ocean water and subsequent salt water corrosion and exposure to ocean currents for almost 60 years. These conclusions apply to potential exposure in 2011 when the San Clemente Island divers got close to the sunken vessel, as well as during the period of use, repair, and multiple refurbishments of SQUAW-29 in the 1960s and 1970s. Furthermore, in the unlikely event that SQUAW-29 was activated or contaminated and any radioactive materials remained today after almost 60 years of environmental exposure and radioactive decay, ocean water surrounding the Squaw will attenuate most gamma and all beta and alpha emissions to a nearby diver. In addition, the depth at which divers found the sunken vessel limits the opportunity and duration for divers to be exposed, and the intervening water would completely shield anyone sailing or swimming on the ocean surface.

Section 5.

References

CHESNAVFACENGCOM (Chesapeake Naval Facilities Engineering Command), 1978. *Squaw Mooring Project, Final Report* (Volume 1 and Volume 2). FPO-1-78(18). Ocean Facilities Engineering and Construction Project Office, CHESNAVFACENGCOM, Washington, D.C. September.

DNA (Defense Nuclear Agency), 1955. *Operation WIGWAM, Report of Commander, Task Group 7.3*, (extracted version), DNA 001-79-C-0455, Defense Nuclear Agency, Fort Belvoir, VA. July 22.

DTRA (Defense Threat Reduction Agency), 2010. *Standard Operating Procedures Manual for Radiation Dose Assessment, Revision 1.3/1.3a*. DTRA-SOP-10-01. Defense Threat Reduction Agency, Fort Belvoir, VA. January 31/March 31.

DTRA (Defense Threat Reduction Agency), 2014. *Operation WIGWAM Fact Sheet*, Defense Threat Reduction Agency, Fort Belvoir, VA. May. http://www.dtra.mil/Portals/61/Documents/NTPR/1-Fact_Sheets/17_WIGWAM.pdf. Accessed April 26, 2016.

Focke, A.B., 1980. *Scientific Director's Summary Report, Operation WIGWAM* (extracted version), WT-1003 (EX). Defense Nuclear Agency, Washington, DC. February 1.

Gladeck, F.R., Gould, K.G., Hallowell, J.H., Martin, E.J., McMullan, F.W., Miller, R.A., Osborn, M.J., Shelton, C.F., Berkhouse, L., and Calhoun, F.S., 1982. *Operation HARDTACK I: 1958*. DNA 6038F. Kaman Tempo, Santa Barbara, CA. December 1.

Hicks, H.G., 1982. "Calculations of the Concentration of any Radionuclide Deposited on the Ground by Offsite Fallout from Nuclear Detonation," *Health Physics*, 42(5): 585–600.

Madden, N., 2014. Public inquiry received by DTRA Public Affairs, from Ned Madden of the OC Weekly, Costa Mesa, CA. April 21.

Marco, P., 2015. "San Clemente Island's Mystery Wreck," amateur video posted at https://vimeo.com/20050159. Accessed May 2, 2016.

NAVSHIPS (Naval Ship Systems Command), n.d. (circa 1971). *The Squaw, Technical Report on Submerged Submarine Hull Target*. NAVSHIPS 0994-011-2010. Department of the Navy, Naval Ship Systems Command, Washington, D.C.

NNDC (National Nuclear Data Center), 2015. *Chart of the Nuclides*. National Nuclear Data Center, Brookhaven National Laboratory. http://www.nndc.bnl.gov/chart/. Accessed April 26, 2016.

NOAA (National Oceanic and Atmosphere Administration), 2015. "Bathymetric Data Viewer," National Centers for Environmental Information (NOAA), Boulder, CO. http://maps.ngdc.noaa.gov/viewers/bathymetry/. Accessed April 26, 2016.

Rebreather World, 2011. Rebreather World Forum, posts on Feb 18–21, 2011. http://www.rebreatherworld.com/showthread.php?37148-San-Clemente-Island-s-Mystery-Wreck. Accessed April 26, 2016

Rich, H.L., Weinberger, F., Habib, E.T., Bort, R.L., and Sette, W.J., 1985. *Operation Hardtack–Project 3.5, Loading and Response of Submarine Hulls from Underwater Bursts*. WT-1629 (EX). David Taylor Model Basin, Washington, D.C. September 1.

Ross, W.J., 1955. *Project 3.8, Design and Construction of WIGWAM Targets*. WT-1031, Report to the Scientific Director, Operation WIGWAM, Long Beach Naval Shipyard, Long Beach, CA. May.

Schaeffer, N.M. (ed), 1973. *Reactor Shielding For Nuclear Engineers*. U.S. Atomic Energy Commission, Office of Information Services. May. http://pbadupws.nrc.gov/docs/ML1000/ML100070680.pdf. Accessed April 26, 2016

USAF (United States Air Force), 1955. *Nuclear Test Film–Operation Wigwam*. United States Air Force Lookout Mountain Laboratory, Hollywood, CA. https://archive.org/details/gov.doe.0800018. Accessed April 26, 2016.

Voss, J.T., 2001. *Los Alamos Radiation Monitoring Notebook* originally June 2000. LA-UR-2584. Feb. http://www.nrrpt.org/documents/la-ur-00-2584.pdf. Accessed April 26, 2016.

Weary, S.E., Ozerroff, W.J., Sperling, J.L., Collins, B., Lowery, C.W., and Obermiller, S.K., 1981. *Operation WIGWAM*. DNA 6000F. Defense Nuclear Agency, Washington, DC. September 1. http://www.dtra.mil/Portals/61/Documents/NTPR/2-Hist_Rpt_Atm/1955_DNA_6000F.pdf. Accessed April 26, 2016.

Abbreviations, Acronyms, and Unit Symbols

CHESNAVFACENGCOM	Chesapeake Naval Facilities Engineering Command
Ci	curie
Co-60	Cobalt-60 (radioactive isotope of cobalt)
d	day
DNA	Defense Nuclear Agency
DTRA	Defense Threat Reduction Agency
Fe-55	Iron-55 (radioactive isotope of iron)
ft	feet
h	hour
kt	kiloton
m	meter
mi	mile
MCi	Mega-curie
MeV	Mega-electron volt
mrad	milli-rad (= 0.001 rad, a unit for radiation absorbed dose)
n.d.	No date
NAVSHIPS	Naval Ship Systems Command
NNDC	National Nuclear Data Center
NOAA	National Oceanic and Atmosphere Administration
NTPR	Nuclear Test Personnel Review
R	Roentgen (a unit for radiation exposure)
USAF	United States Air Force
WWII	World War Two